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"Turbulent Boundary Layer Structure and Drag Reduction"

by

M.T. Landahl

and

S.E. Widnall

(Principal Investigators)

SUMMARY

During the present grant period, the research work has progressed along the following lines: 1) completion of the work on the evolution of a localized eddy in a parallel invis*s*cid shear flow; 2) ~~ii)~~ development of a theory for coherent structures in wall-bounded turbulence; 3) ~~iii)~~ experimental studies of natural and artificially-generated transition in plane channel flow; 4) ~~iv)~~ work on the development of a generalized theory for propagation of waves with small dissipation through homogeneous or non-homogeneous media with application to wave trains or wave packets in shear flows. *Eddies fluid mechanics;*

Theoretical Results

During the present period of research, the work on the evolution of a localized eddy in a parallel inviscid shear flow has been completed. The work is described in the Ph. D. thesis by J.Russell (Russell, 1981) entitled "The Evolution of a Flat Eddy

Near a Wall in an Inviscid Shear Flow". In this work it is demonstrated that the initial phase of the evolution of a three-dimensional eddy of large horizontal scale (compared to its vertical scale) is controlled primarily by horizontal inertia and continuity. Pressure gradient effects are found to be small during the early evolution, especially in the case of the boundary layer, as was suggested by Landahl (1978). The new improved theory allows arbitrarily large-amplitude disturbances to be treated and it takes pressure into account by means of a Taylor series expansion in time using the first four terms. The results show that the three-dimensional disturbance will evolve into a sharp internal shear layer which intensifies with time, as was first found in the simplified treatment by Landahl (1978), using a linearized approximation with the effects of pressure omitted. These results may be significant for the understanding of how a turbulent burst contains its own seed for regeneration of the next burst downstream. Two manuscripts on this work are in preparation for submission to the Journal of Fluid Mechanics.

In an effort to gain a theoretical understanding of experiments based on conditional sampling, a theoretical model for coherent structures in wall turbulence has been worked out (Landahl, 1980). In this, the assumption of large horizontal scale of the coherent structures is employed, as in the study of the flat eddy above, and the evolution equation for the coherent, conditionally sampled eddy is solved in the same manner using a Lagrangian technique. The theory is exemplified by an application of the Laufer-Kaplan VITA technique.

The sampled velocity field obtained from this theory shows qualitatively good agreement with the experimental data by Blackwelder & Kaplan (1976). Thus, the theory shows the characteristic slowdown of the velocity before the onset of a large acceleration at the time of detection of the structure followed by a slow deceleration back to the undisturbed mean flow. Also, it shows the formation of a thin shear layer at later times which is highly tilted in the streamwise direction, as has been observed by Kreplin & Eckelmann (1979) in their oil-flow experiments. The shear layers form under a depression of the outer streamlines followed downstream by a bulge, highly reminiscent of the qualitative spatial structure suggested by the experimental observations by Brown & Thomas (1977).

In view of our experimental results(see below) that demonstrate the importance of wave propagation and breakdown for sustaining turbulence in wall-bounded shear flows, we have begun work on a general theory for the behavior of waves in a shear flow. This theory allows the calculation of slightly dissipative wave trains and wave packets in both uniform and non-uniform media. A report on this work is in preparation and will be issued under the continuation grant.

2b) Experimental Results

The flow visualization studies of transition spots in plane Pouisielle flow have been dramatically sucessful. A paper on the results of this study has been prepared, Carlson et al. (1981), and submitted to the Journal of Fluid Mechanics. A paper on this experiment was also presented at the annual meeting of the Division of Fluid Dynamics of the American Physical Society (Widnall et al., 1981). Our studies of artificially triggered transition in plane Poiseuille flow in a water channel by means of 10-20 micron titanium dioxide-coated mica particles have revealed some striking features of turbulent spots. This method allows visualization of flow phenomena that do not remain with the fluid particle, and unlike tracer methods (ink, smoke or bubbles), allows the visualization of waves that travel through the flow.

Strong oblique waves, thought to be Tollmien-Schlichting waves, were observed both at the front of the arrowhead-shaped spot as well as trailing from the rear tips. Both natural and artificially triggered transition were observed to occur for Reynolds numbers slightly above 1000, above which the flow became fully turbulent. These waves may be related to the velocity-vorticity resonance, investigated by Gustavsonn and Hultgren (1980) and applied to plane Poisueille flow by Gustavsonn (1980). This theory predicts algebraic growth, with long-time slow exponential decay, of certain oblique Tollmien-Schlicting waves.

Video-taped records of spot development show that the front of the spot moves with a convection speed of about 2/3 the centerline velocity while the rear portion moves at about 1/3 U_{cl}. The spot expands into the flow with a spreading half-angle of about 8 . After growing to a size of some 35 times h (the channel depth) at a downstream distance x/h of about 130, the spot began to split into two spots, accompanied by strong wave activity. The spot(s) could be followed visually downstream of its origin a distance x/h of about 300.

Breakdown to turbulence was observed to occur on the wave crests and to be highly correlated with the wave field. These results indicate that wave propagation and breakdown play a crucial role in transition to turbulence in Poiseuille flow. We believe that such wave activity is an important cause of continued breakdown in wall-bounded turbulent flows.

Striking similarities as well as some differences were observed between transition spots in a channel flow as compored to those in a boundary layer. The observed strong wave activity is felt to be a characteristic of both types of spots; our flow visualization made visible what had been suggested by the hot-wire measurements of Wygnanski, Haritonidis and Kaplan (1978) that Tollmien-Schlicting waves play an important role in the breakdown to turbulence.

The observation of the splitting of the spot has not been reported for boundary layers. The role of the bounded geometry in removing the free stream as a possible source for new energy to sustain the flow, and the subsequent relaminarization of the center of the spot should proved an important input to the development of theoretical models of turbulence.

REFERENCES. (+ supported under the present Grant)

Blackwelder, R. F. & Kaplan, R. E. 1976, On the Wall Structure of the Turbulent Boundary Layer. J. Fluid Mech., Vol 76, 89-112

Brown, G. L. & Thomas, A. S. W. 1977, Large Structure in a Turbulent Boundary Layer. Phys. Fluids, 20, No 10, Part II, pp. S243-S252.

+ Carlson, D. R., Widnall, S. E., and Peeters, M. F. 1981, A Flow Visualization Study of Transition in Plane Poiseuille Flow, submitted to the Journal Of Fluid Mechanics

+ Gustavsson, L. H. 1981, Resonant Growth of Three-Dimensional Disturbances in Plane Poiseuille Flow. J. Fluid Mech. (accepted for publication)

Gustavsson, L. H. & Hultgren, L. S. 1980, A Resonance Mechanism in Plane Couette Flow. J. Fluid Mech., Vol 98, p149.

Kreplin, H. P. & Eckelmann, H. 1979, Propagation of Perturbations in the Viscous Sublayer and Adjacent Wall Region. J. Fluid Mech., Vol 95, 305-322.

+ Landahl, M. T. 1978 Modeling of Coherent Structure in Boundary Layer Turbulence. Proceedings, AFOSR/Lehigh Workshop on Coherent Structure of Turbulent Boundary Layers, pp. 340-371.

+ Landahl, M. T. 1980, A Theoretical Model for Coherent Structures in Wall Turbulence. ICHMT/IUTAM Symposium on Heat And Mass Transfer and the Structure of Turbulence, Dubrovnik, Jugoslavia, Oct 5-11, 1980

+ Landahl, M.T. and Russell, J.M. "A Stastistical Model for Large Scale Coherent Structures in a Turbulent Boundary Layer" paper in preparation

+ Russell, J.M. 1981, "The Evolution of a Flat Eddy Near a Wall in an Invicid Shear Flow", ScD thesis, Department of Aeronautics and Astronautics, MIT

+ Russell, J.M. and Landahl, M.T."The Evolution of a Flat Eddy Near a Wall in an Invicid Shear Flow" paper in preparation

+ Widnall, S.E., Carlson, D.R., Ackmandor, S., and Peeters, M. 1981, "Experimental Studies of Transition in Plane Poiseuille Flow", APS/DFD meeting, Monterey, Calif. Naval Post-Graduate School

Wygnanski, I., Haritonidis, J. and Kaplan, R. E., 1979, On a Tollmien-Schlichting Wave Packet Produced by a Turbulent Spot, J. Fluid Mech., Vol 92, pp505-528